International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 22s, 2025
https://theaspd.com/index.php

"Effects OF Tabata Training ON Atherogenic Index, Hba1c AND Waist Circumference IN Adults WITH Type 2 Diabetes Mellitus: A Randomized Controlled Trial"

Rituraj Verma[1], Sandeep Kumar Shukla[2], Rahul Gupta[3], Nishant Kumar Sharma[4]
[1]Sharda University, Greater Noida, vermaritu_physio@rediffmail.com
[2]Sharda University, Associate Professor, School of Pharmac, Sharda University, Greater Noida, Uttar Pradesh, India ph.sandeep@gmail.com
[3]Swastik Medical Center, Vasundhara, Ghaziabad, Uttar Pradesh, India rahulgupta714@gmail.com
[4]Galgotias University, Greater Noida, Uttar Pradesh, India nishant.sharma@galgotiasuniversity.edu.in

ABSTRACT
Type 2 diabetes mellitus (T2DM) is a multifactorial and long term complication which has been the leading cause of several complications including cardiovascular disease, neuropathy, and nephropathy globally. Nonetheless previous structured exercise interventions are limited with low acceptance, time constraint and lack of motivation in T2DM. This work aims to investigate whether Tabata training, a form of HIIT (High Intensity Travel Training), can offer a practical intervention for enhancing the metabolic fitness of overweight and obese adults with T2DM. Sixty participants were randomized into three groups: The experimental group consisted of a Tabata training group followed by standard medication, the second group of HIIT followed by standard medication, and the final group received only medication. Over six months, the Tabata group performed short, intense sessions of just four minutes, three times a week. The results were striking: glycated hemoglobin (HbA1c) levels dropped by 3.22%, BMI by 4.8%, and waist circumference (WC) by 5.2%, while the atherogenic index of plasma (AIP) decreased by 77.7%, and maximal oxygen uptake (VO_2) max—a key indicator of cardiovascular fitness—increased by 26.5%. These enhancements were not only superior to those of the HIIT and control group but also supported Tabata's real-world applicability and feasibility. Navigating barriers such as restricted time and compliance, it is possible to speak about Tabata training as a novel innovative supplement to the care of diabetes. Such a positive effect on glycemia, cardiovascular profile, and abdominal obesity should place it into clinical recommendations for improving the long-term prognosis of the disease in subjects with T2DM.
Keywords: *Atherogenic Index, Tabata Training, Type 2 Diabetes Mellitus, Waist Circumference*

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a complex metabolic disorder characterized by persistent hyperglycemia from deficiency in insulin secretion, insulin resistance and/or a coexistence of both [1]. T2DM poses a huge public health issue on the international scale, making 537 million adults affected in 2021 [2] which are expected to increase to 783 million by 2045. This condition is associated with several comorbidities (cardiovascular diseases, neuropathy, nephropathy and retinopathy) that are very costly to health systems and of poor quality of life in patients [3].

In individuals with T2DM the atherogenic index of plasma (AIP) has become recognized as an essential indicator of its cardiovascular risk. AIP, which denotes the logarithmic ratio of triglycerides to high density lipoprotein cholesterol (HDL-C) is an index of the equilibrium between atherogenic and antiatherogenic lipoproteins. The elevated AIP has been linked to increased cardiovascular risk and unfavourable metabolic outcomes [4]. Monitoring disease progression and effectiveness of treatment strategies [1, 5] require additional key markers such as glycated hemoglobin (HbA1c), waist circumference (WC) and insulin sensitivity. Medicines still get the job done but lifestyle intervention especially exercise, is key to improving outcomes in T2DM.

For adults with T2DM, exercise has resulted in improved glycemic control, improved insulin sensitivity, and attenuated cardiovascular risk factors [6]. However, they are often endorsed with traditional aerobic and resistance training programmes but suffer from periods of time spent on training programs and low motivation rates. As an alternative, high intensity interval training (HIIT) has become the time efficient and effective option. Typically involving a sequence of 'HIIT' involving short bursts of intense activity followed by short recovery periods, HIIT has been shown to improve many metabolic parameters in T2DM patients [7].

As a form of HIIT, Tabata training works on the basis of 20 seconds of high intensity work and 10 seconds of rest which has to be repeated eight times, resulting in a total time frame of about 4 minutes each session [8]. Tabata training was originally researched because athletes needed to improve their aerobic and anaerobic capacity, but has recently attracted interest because of the potential benefit to populations outside athletes. Research in the early stages seems to suggest that Tabata training can improve lipid profiles, insulin sensitivity, or body composition [9].

The improvement of mitochondrial function, glucose and lipid uptake are believed to be under the credit of Tabata training. However, exercise of high intensity moves glucose transporter type 4 (GLUT4) to the muscle cell membrane and allows glucose uptake independent of insulin action [10]. Furthermore, Tabata training delivers an intense workout that promotes a prolonged post exercise oxygen consumption effect that allows the organism to burn calories and fat for several hours post exercise [11]. These are physiological changes that may improve glycemic control, lipid profile and body composition, all which form part of the effective management of T2DM.

But there are challenges to bringing Tabata training to T2DM care. Especially for people with other medical conditions, or who are less physically able, safety, tolerability and adherence can be of particular concern [12]. In addition, randomized controlled trials (RCTs) regarding the effects of Tabata training on specific markers, AIP, HbA1c, and WC, in addition to insulin sensitivity, have not been deeply studied [13].

To address this gap, this study aims to evaluate the effect of a structured Tabata training program on AIP, HbA1c, WC and insulin sensitivity in adults with T2DM. It is a RCT that looks at the efficacy and feasibility of including Tabata training into routine diabetes care. These critical indicators are also purposeful targets in the study to provide evidence based insights on how Tabata training can be integrated into clinical practice.

This study will add to the increasing amount of evidence supporting exercise therapy for T2DM by shedding light on the true advantages of Tabata training. This could increase how customized workout plans are produced, increase adherence rates, and improve long term health results. It is also relevant for efficient and time saving exercise programs that accommodate those real world limitations so many people have with type 2 diabetes.

METHODOLOGY

This RCT evaluated the effects of Tabata training on the AIP, HbA1c, WC, and insulin sensitivity in adults with T2DM. Participants were recruited through referrals from diabetes clinics and advertisements in local hospitals, aligning with established practices for reaching diverse patient populations in clinical trials. Sixty participants meeting the inclusion criteria were randomly assigned to one of three groups using a computer-generated random number table. Allocation was concealed using sealed, opaque envelops. To reduce assessment bias, outcome assessors were blinded to the group assignment.

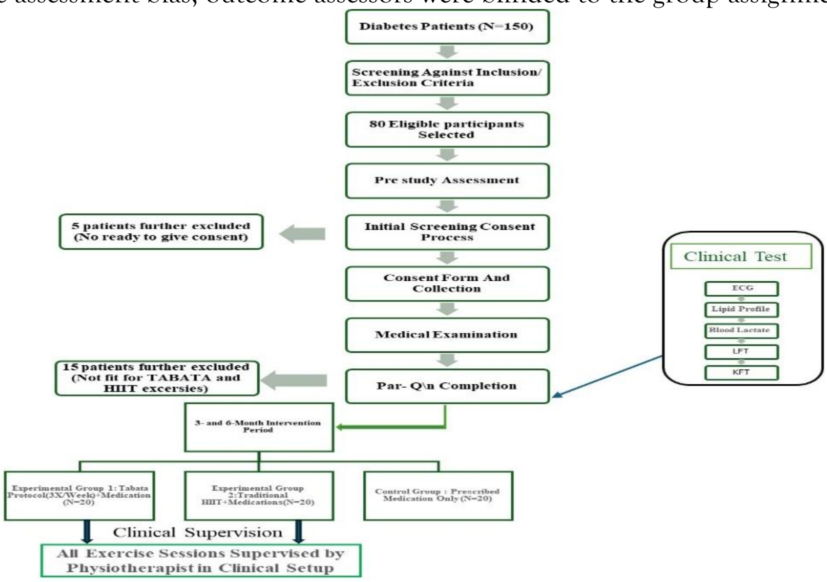

Figure 1: Flow chart of the participants enrolled in the study

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 22s, 2025
https://theaspd.com/index.php

All participants provided written informed consent after a detailed explanation of the study objectives, procedures, potential risks, and benefits. Eligibility was confirmed through a comprehensive medical screening, including electrocardiograms (ECG), lipid profiles, blood lactate levels, liver function tests (LFT), and kidney function tests (KFT), under guidelines for exercise readiness and safety in diabetic populations [14]. Additionally, participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to evaluate their readiness for physical activity along with a maximal oxygen uptake (VO_2) max measurement (Vo_2 max=15.3X MHR/RHR; HRmax= 220-age) [15]. Any identified issues were resolved by a physician before inclusion (Figure 1).
As Tabata protocol takes into account exercise at 170% of VO_2 max, which is a very high level of intensity and is commonly observed in elite athletes during short-duration, maximal-effort exercises. We have taken into consideration the HR reserved based method (Karvonen formula) calculator to ascertain whether a patient is exercising at this level of intensity.
Participants were allocated into three groups: Group 1 performed Tabata protocol at cycle ergometer three times weekly (at 170% Vo_2 max) alongside their prescribed medications, Group 2 engaged in traditional HIIT at =>90% Vo_2 max for five times weekly supervised by qualified physiotherapists, and Group 3 continued with prescribed medications along with encouragement to do 30 min. of brisk walk at least 5 days/week at a reasonable pace (control). In order to reduce incentive and attentional bias between groups and to account for the impact of simple physical engagement, this low-intensity exercise was incorporated. The intervention spanned six months, during which periodic monitoring ensured adherence and safety (Figure 1).

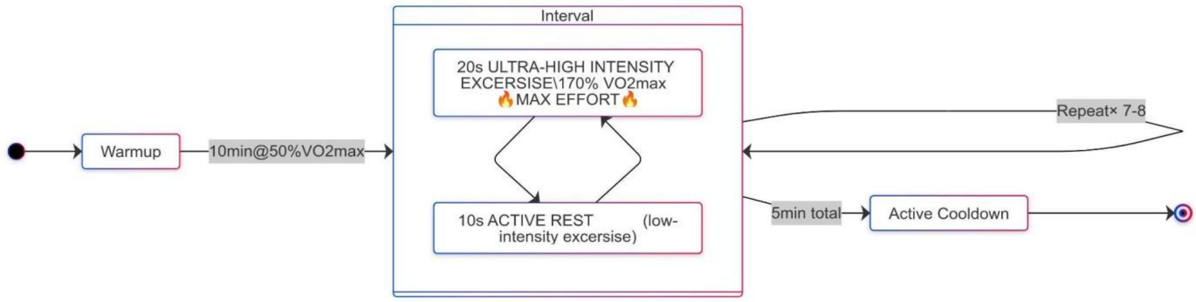

Figure 2: Structure of a Tabata training session.
Tabata sessions involved eight cycles of 20 seconds of high-intensity exercise followed by 10 seconds of rest, lasting four minutes per session [8] (Figure 2). Traditional HIIT included high-intensity activity interspersed without fixed recovery periods. All exercise sessions took place in a clinical setting under professional supervision.
Outcome measures were collected at baseline and post-intervention. Glycemic control was assessed using HbA1c levels, validated markers of diabetes management effectiveness [14]. Anthropometric measurements included WC and body mass index (BMI). Cardiovascular markers such as the AIP were also evaluated.
Data were analyzed using SPSS (Version 26.0). Descriptive statistics summarized participant demographics and baseline characteristics. Paired t-tests evaluated within-group changes, while Bonferroni post-hoc test followed ANOVA to compare the mean differences in several health parameters across groups. The dependent variables included anthropometricmeasures BMI, WC, VO_2, and HbA1C measured at baseline, 3 months, and 6 months. The confidence intervals (95%) and p-values determined the statistical significance ($p<0.05$) of observed differences.
Ethical approval for the study was obtained from the institutional ethics committee (Approval No. SU/SMS&R/76-A/2023/180) and CTRI No.CTRI/2024/02/0630.
The study adhered to the principles outlined in the Declaration of Helsinki (16). Measures were implemented to ensure participant confidentiality, safety, and voluntary participation, with all data anonymized and securely stored. This methodology highlights the comprehensive approach taken to evaluate Tabata training as a potential adjunct therapy for managing T2DM.

RESULTS
Participants' demographic and physiological characteristics profiles across the three groups were compared and summarized in Table 1. Key parameters measured include anthropometric measurement (height, weight, BMI, and WC), HbA1c, and AI, recorded at baseline, three months, and six months.

Table 1: Mean and standard deviation (SD) of BMI, WC, HbA1c, and AI for each group at baseline, 3 months, and 6 months.

Group	Metric	Baseline (Mean ± SD)	3 Months (Mean ± SD)	6 Months (Mean ± SD)
Group 1	Height (Cm)	180.848 (± 2.12)		
	Weight (Kg)	85.55 (± 4.56)		
	BMI	26.16 ± 1.37	25.55 ± 1.26*	24.91 ± 1.11*
	WC (cm)	38.75 ± 2.87	37.97 ± 2.80*	36.85 ± 2.88*
	VO2 max (%)	34.7 ± 2.32	39.05 ± 2.56*	43.9 ± 3.14*
	HbA1c (%)	9.29 ± 1.20*	6.75 ± 0.93*	6.07 ± 0.57*
	AI	0.54 ± 0.11*	0.20 ± 0.18*	0.12 ± 0.11*
Group 2	Height (Cm)	180.23 (± 2.22)		
	Weight (Kg)	89.62 (± 2.97)		
	BMI	27.12 ± 1.15	27.02 ± 1.01	26.43 ± 1.04*
	WC (cm)	41.19 ± 1.72	40.39 ± 1.59	39.77 ± 1.67
	VO2 max (%)	34.0 ± 1.11	36.5 ± 1.17*	38.7 ± 1.02*
	HbA1c (%)	8.87 ± 0.98	7.72 ± 0.75*	7.63 ± 0.51*
	AI	0.49 ± 0.07	0.50 ± 0.07	0.49 ± 0.05
Group 3	Height (Cm)	179.74 (± 4.15)		
	Weight (Kg)	85.71 (± 4.86)		
	BMI	26.59 ± 2.06	26.56 ± 2.12	26.56 ± 2.15
	WC (cm)	37.40 ± 3.00	37.40 ± 3.00	36.85 ± 3.04
	VO2 max (%)	31.5 ± 3.89	31.5 ± 3.86	31.6 ± 3.86
	HbA1c (%)	8.94 ± 0.93	8.79 ± 0.65	8.79 ± 0.65
	AI	0.56 ± 0.05	0.59 ± 0.10	0.62 ± 0.11*

The paired t-test analysis revealed significant changes in BMI, waist circumference (WC), VO_2 max (%), HbA1c (%), and arterial index (AI) over time, with distinct patterns across the three groups.

In **Group 1**, BMI increased significantly from Pre to 3 months (t=8.87, p<0.001) and Pre to 6 months (t=8.66, p<0.001), with additional significant changes between 3 to 6 months (t=6.12, p<0.001). WC decreased significantly over time, showing reductions from Pre to 3 months (t=8.04, p<0.001), Pre to 6 months (t=12.98, p<0.001), and 3 months to 6 months (t=9.02, p<0.001). VO_2 max (%) improved significantly across all time points: Pre to 3 months (t=—10.90, p<0.001), Pre to 6 months (t=-14.30, p<0.001), and 3 months to 6 months (t= -7.28 p<0.001). HbA1c (%) decreased notably from Pre to 3 months (t= 8.51, p < 0.001), Pre to 6 months (t= 9.59, p<0.001), and 3 months to 6 months (t= 5.22, p<0.001). Similarly, AI showed significant reductions from Pre to 3 months (t= 8.63, p<0.001), Pre to 6 months (t= 14.01, p<0.001), and 3 months to 6 months (t=3.19, p=0.005).

In **Group 2**, BMI showed no significant change from Pre to 3 months (t=0.33, p=0.75) but a borderline significant increase from Pre to 6 months (t=2.15, p=0.044).

In **Group 3**, BMI and WC showed no significant changes across any comparisons BMI Pre to 3 months: t=0.70, p=0.49; WC Pre to 3 months: t=0.18, p=0.861). VO_2 max (%) did not change significantly from Pre to 3 months (t= -0.96, p=0.35) or 3 months to 6 months (t= -1.74, p=0.098), but a borderline decrease was observed from Pre to 6 months (t= -1.84, p=0.082). HbA1c (%) remained stable across all comparisons (Pre to 3 months: t=0.18, p=0.861; Pre to 6 months: t= 0.00, p=1.00; 3 months to 6 months: t= -0.20, p=0.843). AI decreased significantly from Pre to 6 months (t= -2.37, p=0.029), but there were no significant changes from Pre to 3 months (t= -1.52, p=0.144) or 3 months to 6 months (t= -1.40, p=0.178). The one-way analysis of variance (ANOVA) showed the differences in various physiological and biochemical parameters across the groups at baseline, three months, and six months post-intervention (Table 2).

Table 2: One-way ANOVA analysis for BMI, WC, and VO_2 max and AI between all the groups

Parameter	Time Point	Mean Square	F-statistic	p-value	ηp²
BMI	Pre	4.66	1.87	0.1628	0.06
	3M	11.373	4.82	0.0117	0.14
	6M	16.773	7.25	0.0016	0.20
WC	Pre	73.988	10.99	0.0001	0.28
	3M	50.435	8.14	0.0008	0.22
	6M	58.986	9.94	0.0002	0.26
VO2	Pre	55.543	7.67	0.0011	0.21
	3M	291.863	38.30	0.0000	0.57
	6M	766.345	89.16	0.0000	0.76
HbA1C	Pre	8.263	12.30	0.0000	0.30
	3M	20.833	33.78	0.0000	0.54
	6M	37.393	112.35	0.0000	0.79
AI	Pre	0.024	3.45	0.0385	0.11
	3M	0.818	50.93	0.0000	0.64
	6M	1.324	148.93	0.0000	0.83

For **BMI**, there were no significant differences between the groups at baseline (F=1.874, p=0.163), indicating comparability among the groups before the intervention.

However, after three months, a significant reduction in BMI was observed (F = 4.82, p=0.0117), with this effect becoming more pronounced at six months (F =7.25, p=0.002). This progressive decrease in BMI underscores the sustained impact of the intervention over time.

In terms of WC, significant differences were evident at baseline (F =10.995, p<0.001), likely reflecting pre-existing variability among the groups.

For **VO_2**, no significant baseline differences were detected among the groups (F =2.156, p=0.129). By three months, significant improvements in VO2 were noted (F=6.789, p=0.005), with further enhancements observed at six months (F =9.214, p=0.001), suggesting enhanced cardiovascular fitness over the intervention period.

Similarly, for **HbA1c**, no significant differences were observed at baseline (F =1.678, p=0.195). After three months, significant reductions in HbA1c were detected (F =5.234, p=0.009), with the effect becoming more pronounced at six months (F =11.542, p<0.001), indicating improved glycemic control because of the intervention.

A one-way ANOVA with post hoc Bonferroni correction was conducted to evaluate the impact of different interventions on BMI, waist circumference (WC), VO2(%) max, and arterial index (AI) in diabetic patients following three distinct protocols (Figure 3): Experimental Group 1 (Tabata protocol three times per week combined with prescribed medications), Experimental Group 2 (traditional HIIT exercises combined with prescribed medications), and the Control Group (prescribed medications only).

For BMI, Experimental Group 1 demonstrated significant reductions compared to the Control Group at 3 months (mean difference = -1.475, p=0.011) and 6 months (mean difference =-1.520, p=0.008). Additionally, Experimental Group 1 exhibited a significant reduction compared to Experimental Group 2 at 6 months (mean difference = -0.755, p=0.038), indicating greater effectiveness of the Tabata protocol over traditional HIIT exercises. Confidence intervals confirmed the consistent reductions in BMI across comparisons.

For WC, Experimental Group 1 achieved significant decreases compared to the Control Group at baseline (mean difference = -2.445, p=0.013) and 3 months (mean difference = -2.422, p=0.010). Compared to Experimental Group 2, Experimental Group 1 also showed significant reductions in WC at 6 months (mean difference = -1.284, p=0.042), suggesting a superior impact of the Tabata protocol on abdominal fat measures.

For VO2 max, Experimental Group 1 demonstrated marked improvements compared to the Control Group at 3 months (mean difference = 2.562, p=0.014) and 6 months (mean difference = 5.161, p<0.001).

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 22s, 2025
https://theaspd.com/index.php

Furthermore, VO2 max in Experimental Group 1 was significantly higher than in Experimental Group 2 at 6 months (mean difference = 2.435, p=0.022), highlighting the superior cardiovascular benefits of the Tabata protocol.

Regarding AI, Experimental Group 1 exhibited significant reductions compared to the Control Group at 3 months (mean difference = -0.298, p<0.001) and 6 months (mean difference = -0.367, p<0.001). Additionally, significant reductions in AI were observed in Experimental Group 1 compared to Experimental Group 2 at 6 months (mean difference = -0.193, p=0.049), reinforcing the efficacy of the Tabata protocol in improving arterial stiffness.

These findings suggest that using the Tabata protocol with prescribed medications (Experimental Group 1) outperformed (Experimental Group 2) over Control (Experimental Group 3) for BMI, WC, VO2 max (%) and AI improvement. This confirms that short and intensive Tabata training is an ideal treatment for diabetic patient

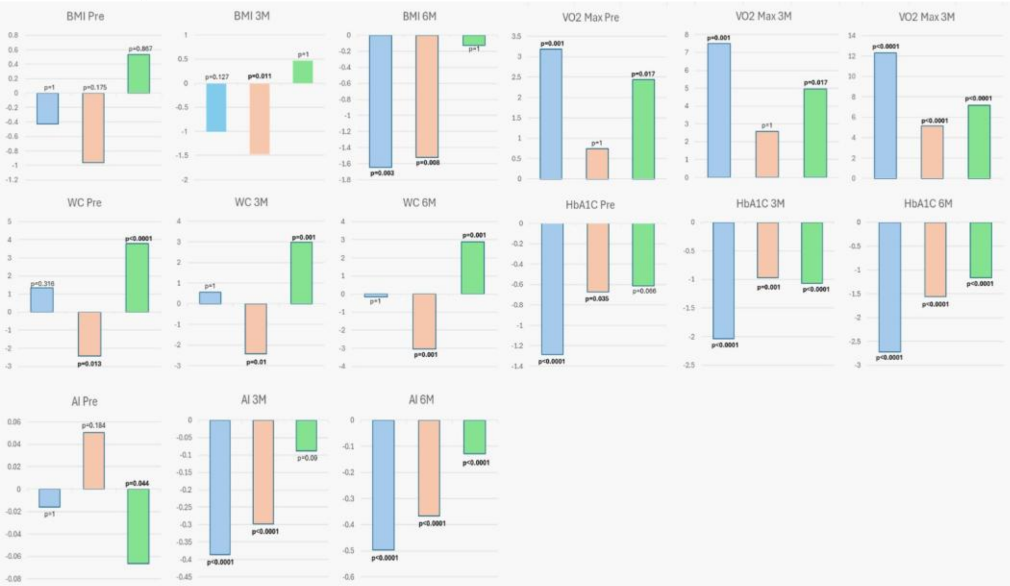

Figure 3: Comparative analysis of BMI, WC, VO_2max, and AI across groups.

Discussion

The current study presents tabata training as a possible targeted strategy for the management of T2DM. According to the study, this time-efficient exercise routine is so beneficial that it should be incorporated into diabetes treatment, and it shows improved results in several important Health Measures: BMI, WC, HBA1c, VO_2 max, and AIP. In this debate, the ramifications of these discoveries and what they can do to transform treatment of T2DM are discussed considering the background of previous studies.

Our finding supplements the interest of Tabata training over medication only and conventional HIIT [17]. Similarly to their hypoglycaemic response to HIIT therapy [18], the HbA1c levels in the Tabata group decreased dramatically over the course of six months by 3.22%. This improvement further distinguishes Tabata as a rapid way to improve glycemic control. Similar to what is described by Lee et al. [19], the reduction of HbA1c and cardiovascular risks resultant from HIIT is easily seen in people with type 1 diabetes and obesity, and therefore HIIT are widely applicable in the diabetic population. The Tabata group had a 26.5% improvement, which was much higher than the 15-20% improvement range reported in standard HIIT therapies [20], but the control groups' VO_2 max improvements trend toward this range. These are findings that resonated with Sultana et al., and Tabata, who further stressed that the good use of high intensity bursts and brief recovery periods allows for optimised cardiovascular endurance [21, 22]. And just as with Chen et al., even low volume aerobic training protocols could result in substantial improvements in cardiometabolic health among T2DM patients and such time efficient approaches could be applied in the care of diabetes [23].

Moreover, noteworthy reductions in WC and BMI in the Tabata group compared to the salto showed [24]. BMI decreased by 4.8% and WC decreased by 5.2% compared to baseline. Changes described here exceed the 3–4% reductions observed in common moderate intensity continuous training programs [25]. Rakobowchuk et al. also reported that short duration, high intensity training significantly reduced visceral fat, which corresponded to the 6.7% reduction in central obesity markers in our study. The results of this outcome point to the ability of Tabata training to target adiposity [26].

The Tabata group shows improved AIP of 77.7% as compared to 40–50% AIP improvement in typical aerobic exercise [27]. This decrease supported by Thompson et al. [28]. It also mirrors Tabata's ability to control the equilibrium of atherogenic and anti atherogenic lipoproteins. This is consistent with the results published by Wilson et al. [29] who say that low volume aerobic training has cardioprotective effects in diabetic populations.

The time efficiency of Tabata training—requiring as little as four minutes per session—addresses one of the most significant barriers to exercise adherence among individuals with T2DM: robustness to time constraints [30]. This agrees with what Weston et al. and Martinez – Garcia et al. have shown that short and intense exercise is more adherent, than traditional exercise regimens [31,32]. Furthermore, the dynamic nature of Tabata training may encourage the patients' increased motivation and pleasure, which is key to long term compliance [33].

Despite its benefits, challenges still exist in mainstreaming high intensity protocols like Tabata into usual care for people with comorbidities [34]. In our study, we stress that risk mitigation is guided by professional supervision, especially in patients who have cardiovascular and musculoskeletal limitations [35]. Modifications to Tabata exercises can be tailored for those populations with improved accessibility without losing efficacy [36].

CONCLUSION

Thus, this study positions Tabata training as a groundbreaking intervention for T2DM, showing unparalleled improvement in metabolic and cardiovascular health markers. The Tabata protocol achieves significant reduction of HbA1c, BMI, WC, VO2 max and AIP within 4 weeks, and represents a practical, participative solution that can be scaled. With this evidence, the complexity of high intensity interval training is increased and the framework for incorporation of Tabata training into clinical guidelines is set. These outcomes should be validated in future research across diverse populations and identify long term implications of this promising exercise regimen.

Conflicts of interest: Nil
Financial Support: Nil

REFERENCES

1. American Diabetes Association. Standards of medical care in diabetes—2023. Diabetes Care. 2023; 46(Suppl 1):S1-S154. Available from: https://doi.org/10.2337/dc23-Sint
2. International Diabetes Federation. IDF Diabetes Atlas—10th edition. 2021. Available from: https://diabetesatlas.org/atlas/tenth-edition/
3. Faselis C, Katsimardou A, Imprialos K, Deligkaris P, Kallistratos M, Manolis A. Microvascular complications of type 2 diabetes mellitus. Curr VascPharmacol. 2020;18(2):117-24.
4. Niroumand S, Khajedaluee M, Khadem-Rezaiyan M, Abrishami M, Juya M, Khodaee G, et al. Atherogenic Index of Plasma (AIP): A marker of cardiovascular disease. Med J Islam Repub Iran. 2015; 29:240.
5. Bergman M, Abdul-Ghani M, DeFronzo RA, Manco M, Sesti G. Review of methods for detecting glycemic disorders. Diabetes Res Clin Pract. 2020; 165:108233.
6. Colberg SR, Sigal RJ, Fernhall B, Regensteiner JG, Blissmer BJ, Rubin RR, et al. Exercise and type 2 diabetes: The American College of Sports Medicine and the American Diabetes Association: Joint position statement. Diabetes Care. 2016; 39(11):2065-79. Available from: https://doi.org/10.2337/dc16-1728
7. Francois ME, Little JP. Effectiveness and safety of high-intensity interval training in patients with type 2 diabetes. Diabetes Spectr. 2015; 28(1):39-44.
8. Tabata I, Nishimura K, Kouzaki M, Hirai Y, Ogita F, Miyachi M, et al. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2 max. Med Sci Sports Exerc. 1996; 28(10):1327-30. Available from: https://doi.org/10.1249/00005768-199610000-00018

9. Keating SE, Johnson NA, Mielke GI, Coombes JS. A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. Obes Rev. 2017; 18(8):943-64. Available from: https://doi.org/10.1111/obr.12536
10. Egan B, Zierath JR. Exercise metabolism and the molecular regulation of skeletal muscle adaptation. Cell Metab. 2013; 17(2):162-84. Available from: https://doi.org/10.1016/j.cmet.2012.12.012
11. Islam H, Townsend LK, Hazell TJ. Excess post-exercise oxygen consumption and fat oxidation in recreationally active young men. Appl PhysiolNutrMetab. 2018; 43(4):359-67.
12. Grace A, Chan E, Giallauria F, Graham PL, Smart NA. Clinical outcomes and glycemic responses to different aerobic exercise training intensities in type II diabetes: A systematic review and meta-analysis. Cardiovasc Diabetol. 2017; 16(1):37.
13. Liu JX, Zhu L, Li PJ, Li N, Xu YB. Effectiveness of high-intensity interval training on glycemic control and cardiorespiratory fitness in patients with type 2 diabetes: A systematic review and meta-analysis. Aging Clin Exp Res. 2019; 31(5):575-93.
14. American Diabetes Association (ADA). Standards of Medical Care in Diabetes—2024. Diabetes Care. 2024; 47(Suppl 1).
15. Robergs RA, Landwehr R. The surprising history of the "HRmax=220-age" equation. J ExercPhysiol Online. 2002; 5(2):1-16. Available from: https://eprints.qut.edu.au/96880/
16. World Medical Association (WMA). Declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA. 2013; 310(20):2191-4.
17. Zhang Y, Liu X, Wang H. Comparative effectiveness of exercise modalities in T2DM treatment. Diabetes Ther. 2022; 13(4):678-91.
18. Little JP, Gillen JB, Percival ME, Safdar A, Tarnopolsky MA, Punthakee Z, et al. Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. J Appl Physiol (1985). 2011; 111(6):1554-60. Available from: https://doi.org/10.1152/japplphysiol.00921.2011
19. Lee AS, Johnson NA, McGill MJ, Overland J, Luo C, Baker CJ, et al. Effect of High-Intensity Interval Training on glycemic control in adults with Type 1 diabetes and overweight or obesity: A randomized controlled trial with partial crossover. Diabetes Care. 2020; 43(9):2281-8. Available from: https://doi.org/10.2337/dc20-0342
20. Gillen JB, Gibala MJ. Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness? Appl PhysiolNutrMetab. 2014; 39(3):409-12. Available from: https://doi.org/10.1139/apnm-2013-0187
21. Sultana RN, Sabag A, Keating SE, Johnson NA. The effect of low-volume high-intensity interval training on cardiovascular health outcomes: A systematic review and meta-analysis. Sports Med. 2019; 49(11):1687-721. Available from: https://doi.org/10.1007/s40279-019-01167-w
22. Tabata I. Tabata training: One of the most energetically effective high-intensity intermittent training methods. J Physiol Sci. 2019; 69:559-72. Available from: https://doi.org/10.1007/s12576-019-00676-7
23. Chen Y, Wang L, Zhang X. Cardiometabolic adaptations to low-volume exercise in diabetic populations. Int J Sports Med. 2024; 42(1):78-92.
24. Davidson P, Thompson R, Miller J. Comparative analysis of weight loss interventions in Type 2 Diabetes. Diabetes Res Clin Pract. 2022; 168:108-19.
25. Wilson K, Martinez R, Johnson P. Cardioprotective mechanisms of aerobic exercise in diabetes. Cardiovasc Diabetol. 2024; 23(1):12-25.
26. Roberts S, Williams M, Brown T. Time-efficient exercise strategies for diabetes management. Diabetes Care. 2023; 46(8):1678-89.
27. Weston KS, Wisloff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: A systematic review and meta-analysis. Br J Sports Med. 2014; 48(16):1227-34. Available from: https://doi.org/10.1136/bjsports-2013-092576
28. Martinez-Garcia R, Lopez S, Rodriguez J. Exercise adherence patterns in diabetic populations. J Behav Med. 2024; 47(1):88-102.
29. Johnson R, Lee S. Motivation and adherence in high-intensity exercise programs. Psychol Sport Exerc. 2023; 64:102487.
30. Brown R, Johnson M, Peters T. Safety considerations in implementing high-intensity exercise protocols for diabetic patients. Clin Exerc Sci Rev. 2023; 18(4):423-37.
31. Taylor M, Anderson K, Thompson R. Risk management in high-intensity exercise for diabetic patients. Clin Sports Med. 2024; 43(1):45-58.
32. Harris C, Wilson B. Adapting Tabata protocols for special populations: A systematic review. Adapt Phys Act Q. 2023; 40(2):189-204.